CONTROL OF PIGEONS' PECKING BY TRACE STIMULI¹

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In Experiment I, pigeons' pecking a white key was reinforced with grain when white was immediately preceded by a vertical white line on a green surround, but not by green alone. This procedure produced control of pecking by the line. Next, pecking white was reinforced after vertical line on green, but not after green alone or other orientations of the white line on green. The line-tilt dimension initially did not control pecking, a result that showed that interdimensional (line *versus* no line) training does not always result in dimensional control. Line-tilt control was eventually established but was accompanied by a decrease in interdimensional control. In Experiment II, interdimensional training, with or without a trace interval intervening between line on green or green alone and white, was followed by tests for line-tilt control. While interdimensional control was unaffected by the trace interval, line-tilt control tended to be less with the trace interval. This dissociation of interdimensional and dimensional control, as well as the failure of interdimensional training to produce dimensional control in Experiment I, suggests that the line stimulus is multidimensional.

Key words: trace stimulus control, go-no-go procedure, interdimensional control, intradimensional control, multidimensional control, key peck, pigeons

A controlling relationship between a stimulus and a response exists if responding changes when a particular stimulus is presented or if responding systematically varies as a dimension of such a stimulus is changed.

A controlling stimulus may or may not be actually present at the time of responding. When a controlling stimulus has terminated before responding, the term *trace* control is used. A distinction can be made between "choice" and "go-no-go" trace paradigms. In the former paradigm, exemplified by the delayed response procedure (*e.g.*, Hunter, 1913), the delayed matching-to-sample procedure (*e.g.*, Blough, 1959) and the delayed spatial (*e.g.*, Hearst, 1962) or nonspatial (*e.g.*, Williams, 1971) alternation procedures, the trace stimulus controls responding to one but not a second color, turning right or left, *etc.* In the go-no-go paradigm, exemplified by stimulus-duration experiments (*e.g.*, Catania, 1970; Elsom, 1971; Reynolds, 1966; Reynolds and

Catania, 1962; Stubbs, 1968), the trace stimulus controls whether responding does or does not occur during a stimulus that follows the controlling stimulus.

Apart from the stimulus-duration experiments, in which pigeons have been successfully trained to respond after one but not after a second duration of a visual stimulus, little research appears to have been done on go-no-go trace control. The purpose of the present research was to provide additional data on this variety of control.

EXPERIMENT I

The primary purpose of this experiment was to determine if go-no-go trace control of pigeons' pecking during a white light by a preceding line stimulus could be established. Staddon (1972) suggested that this type of control of pigeons' behavior might not be possible because of memory limitations.

METHOD

Subjects

Three adult King pigeons were maintained at about 85% of their free-feeding weights by mixed grain obtained during sessions and post-

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session supplemental feedings. Water and health grit were continuously available in the home cage. Bird 1 was experimentally naive; Birds 2 and 3 had served in experiments involving stimulus control by color of light but were naive with respect to line stimuli.

Apparatus

A Tech Serv, Inc. Model PS-004 light-proof, sound-attenuating pigeon chamber contained a clear plastic pecking key, a grain feeder, and an Industrial Electronics Engineers' Model 10-0229 projector. The key was mounted behind a 3.2-cm diameter circular opening on one wall of the chamber, directly above the feeder. A force of about 0.2 N was required to operate the key microswitch. The projector was mounted directly behind the key and illuminated the key with a uniform field of red, white, or green light or a 2.54- by 0.32-cm white line in various orientations [$\pm 22.5^\circ$, $\pm 45^\circ$, $\pm 67^\circ$, and 90° from vertical (0°)]. Mixed grain, illuminated by a 7-W lamp, was available for 5 sec during feeder operations. The chamber ventilation fan and approximately 70-dB white noise in the chamber provided additional masking of extraneous sounds. Experimental conditions and data recording were implemented by solid-state and electromechanical circuits.

Procedure

As Birds 2 and 3 had experimental experience, no hopper or key-peck training was necessary. Bird 1 was first trained to eat from the hopper and then to peck a white key for 5-sec access to mixed grain reinforcement. All birds then received sessions at approximately the same time each day, six or seven days per week, for the duration of the experiment. Sessions normally consisted of 120 subject-initiated trials.

Interdimensional training. Birds 1 and 2 were trained for 40 sessions to peck a white key when it was preceded by a white line on a green surround, but not when it was preceded by green alone. Bird 3 received similar training for 60 sessions.

Each trial began with illumination of the response key with red light. The key remained red until pecked once. Then, on a random one-half of the trials, the key became green for 1.5 sec. On the other half of the trials, a white vertical (0°) line was superimposed on green.

Key pecks during either stimulus had no effect. The key became white for 5 sec immediately after both stimuli. A single peck that occurred at least 4.5 sec but less than 5 sec after the start of white produced 5-sec access to grain reinforcement when white was preceded by line on green, but not when white was preceded by green alone. At the end of the white stimulus, the key became dark for a 30-sec intertrial interval. Key pecks during the intertrial interval had no effect.

Combined inter- and intradimensional training. After completing interdimensional training, the birds received 50 (Bird 1) or 60 (Birds 2 and 3) sessions in which various orientations of the white line on green, as well as the vertical line on green and the green surround alone, immediately preceded white. A session generally consisted of 12 blocks of 10 trials. In each block, white was preceded by the 0° line five times, and once by each of the other stimuli (green, $\pm 22.5^\circ$, $\pm 45^\circ$ line tilts for Birds 1 and 2; green, $\pm 45^\circ$, $\pm 67.5^\circ$ line tilts for Bird 3). Within each block, the order of stimuli was random. Reinforcement for pecking white was available after the 0° line but not after any of the other stimuli.

RESULTS

Interdimensional training. Control of pecking the white key by the preceding 0° line was clearly established. During the last three interdimensional training sessions, for example, the response rate during white after 0° line greatly exceeded response rate during white after green alone. Response rate in white during these sessions for Bird 1 was 3.11, 3.47, and 3.42 pecks per second after the 0° line but only 0.24, 0.28, and 0.25 pecks per second after green. Rates for Bird 2 were 1.85, 1.56, 1.39 and 0.03, 0.05, 0.11 pecks per second. Rates for Bird 3 were 2.19, 3.82, 3.33 and 0.08, 0.43, 0.11 pecks per second.

Despite the strong control of responding during white by the antecedent line at asymptote, control was established rather slowly relative to that normally achieved when the controlling stimulus is present at the time of responding. The establishment of control by the line stimulus is shown in Figure 1.

Combined inter- and intradimensional training. Figure 2 shows response rate during white after green and various line tilts for the first and last five sessions of combined inter- and

Fig. 1. Control ratios (ratio of response rate during white after green alone to response rate during white after 0° line on green plus response rate during white after green alone) during each interdimensional training session for each bird. The smaller this ratio, the greater the control.

intradimensional training. With the possible exception of Bird 1, the line-tilt dimension initially did not control responding: response rate during white after the 0° line was not greater than response rate after other orientations. Dimensional control of responding by line orientation was established, however, by the last five sessions of training.

Response rate during white after green increased from the end of interdimensional training to the conclusion of combined training. The effect was to increase the value of the control ratio (the ratio of rate after green to sum of rate after green and after 0° line on green).

DISCUSSION

This experiment demonstrated go-no-go trace control of pigeons' pecking by a stimulus other than duration. Staddon's (1972) failure to establish such stimulus control must have been due to some procedural variation.

The present results provide another demonstration (*cf.* Williams, 1973) that interdimensional training (line and green *versus* green) does not always result in dimensional (line-tilt) control. This finding contrasts with that of Jenkins and Harrison (1960), who found that tone frequency controlled pecking after interdimensional tone *versus* no-tone training.

Fig. 2. Response rate (pecks per second) during white after various orientations of line on green and after green alone for first (crosses) and last (diamonds) five sessions of combined inter- and intradimensional training.

The source of the discrepancy between the present results and those of Williams (1973), and the results of Jenkins and Harrison (1960) is unclear.

The present results bear some similarities to the "divided attention" effect reported by Maki and Leith (1973). In their experiment, pigeons received delayed matching-to-sample training with vertical and horizontal white lines and red and blue. On certain test trials, the sample consisted of a compound of line and color. On these trials, matching accuracy on the ensuing line or color comparison stimuli was lower than when the sample consisted of only line or color. In the present experiment, control by the 0° line, as indexed by the control ratio, was greater during interdimensional training than during combined inter- and intradimensional training. Thus, the presence of intradimensional training conditions seems to weaken control produced by interdimensional training procedures.

EXPERIMENT II

The interval between an antecedent controlling stimulus and responding, called the delay or trace interval, has been shown to reduce the degree of control exerted by the antecedent stimulus in the choice trace-control paradigm (e.g., Blough, 1959; Fletcher, 1965). The present experiment provided information on how trace interval duration affects control in a go-no-go trace paradigm. As far as is known, this question has received no experimental attention. The general strategy was to vary trace interval duration and examine interdimensional line *versus* no line, as well as line-tilt dimensional control at different trace intervals. To ensure that line tilt initially controlled responding, the subjects were taken from an experiment involving intradimensional line-tilt training.

METHOD

Subjects

Two adult King pigeons were maintained at about 80% of their free-feeding weights by mixed grain obtained during sessions and post-session supplemental feedings. Water and grit were continuously available in the home cage. Both birds had intradimensional line-tilt training (Wilkie, 1973) immediately before the present experiment.

Apparatus

The apparatus was identical to that of Experiment I, except that the red projector filter was replaced with a pink one.

Procedure

As both birds had experimental experience, no hopper or key-peck training was necessary. Both birds were first exposed to interdimensional line *versus* no line trace go-no-go conditions similar to that arranged in Experiment I. This training was followed by a test for dimensional control by line tilt. In later stages of the experiment, the trace interval was varied and additional tests for dimensional control by line tilt were given. Most conditions were replicated at least once.

Interdimensional training. Sessions normally consisted of 140 subject-initiated trials identical to those arranged in Experiment I, except that (a) trials began with a pink rather than a red light, (b) the line on green or green alone stimulus had a duration of 5 rather than 1.5 sec, and (c) during some conditions, a 2-sec trace interval, during which the key was dark and pecks ineffective, intervened between offset of line on green, or green, and the white stimulus.

Dimensional control tests. The first 20 to 30 trials of the test session were identical to interdimensional training sessions. These "warm-up" trials were followed by 110 test trials, arranged in 10 blocks of 11 trials. In each block, green preceded white once, the 0° line on green and the 90° line on green preceded white twice, the $\pm 22.5^\circ$, $\pm 45^\circ$, and $\pm 67.5^\circ$ lines on green each preceded white once. (The 90° line tilt was omitted during Bird 4's first test.) Reinforcement for pecking white was available on one of the two times the 0° line on green preceded white. The order of trials within each block, as well as the 0° line on green presentation followed by reinforcement availability, was randomized.

To dissociate the effects of the trace interval arranged during interdimensional training from the effect of the trace interval arranged during tests, the trace interval arranged during different tests was varied.

In each test, the number of pecks in the presence of the white key after the various stimuli was recorded during the last eight blocks of stimuli.

Sequence of training and test conditions. Conditions were designated on the basis of the trace interval arranged during interdimensional training and the subsequent dimensional control test: 2-0, for example, indicates a 2-sec trace interval during training and a 0-sec trace interval during testing. The sequence of conditions for Bird 4 was: 0-0, 0-0, 0-0, 2-2, 2-2, 2-0, 2-0, 2-0, 0-2, and 0-2. The number of training sessions in each condition was: 61, 10, 16, 15, 9, 13, 11, 6, 8, and 11, respectively. The sequence for Bird 5 was: 0-0, 0-0, 2-2, 2-2, 2-0, 2-0, and 0-2. The number of training sessions was 64, 18, 20, 9, 17, 14, and 18, respectively.

RESULTS

Interdimensional training. Control of pecking the white key by the antecedent 0° line on green was clearly established. Further, control was little affected by increasing the trace interval from 0 to 2 sec: control ratio values were more-or-less the same during 0- and 2-sec trace interval sessions. The control ratios for Bird 4 averaged over the last three sessions of each 0-sec trace interval and each 2-sec trace interval condition were 0.063 and 0.041, respectively; corresponding values for Bird 5 were 0.019 and 0.016.

Dimensional control tests. Figure 3 shows response rate in the presence of white when white was preceded by green alone and the various orientations of white line on green. Training at longer trace intervals, regardless of trace interval arranged during testing, lessened

degree of control by the line-tilt dimension. That is, gradients of responding during white after various line tilts were flatter after 2-sec trace interval training than after 0-sec trace interval training. An index of gradient slope or degree of control by tilt is shown in Table 1. The line on green *versus* green alone control ratio for each test is also shown in Table 1. In general, the control ratio was larger during test sessions than during the preceding training sessions. Control by line tilt and line *versus* no-line control during tests were related in a direct but weak manner (Pearson *r* values between the two index values in Table 1 were -0.3 and -0.4 for Birds 4 and 5, respectively).

DISCUSSION

The finding of major interest was the dissociation of interdimensional (line *versus* no-line) and intradimensional (line-tilt) control. Interdimensional control ratios changed little as the trace interval was varied from 0 to 2 sec. On the other hand, control by line tilt was generally less, and sometimes even absent (the 2-2 and 2-0 tests for Bird 4, in particular) after 2-sec trace interval training. Since the two types of control were assessed under different conditions, one could argue that the testing procedure itself resulted in a general decrease in control. Alternately, one could suggest that a "divided control" effect similar to that observed in Experiment I occurred during test sessions. The correlation between degree of

Table 1

Indexes of line-tilt and line *versus* no-line control during various combinations of training and test trace intervals. Line-tilt control was indexed by dividing response rate in white after 0° line by average response rate in white after ±67.5° and 90° line tilt. Line *versus* no-line control was indexed by the control ratio: response rate in white after green divided by sum of rate in white after green and rate in white after 0° line.

Training and Test Trace Interval	Test Number	Bird 4		Bird 5	
		Line-Tilt Control	Control Ratio	Line-Tilt Control	Control Ratio
0-0	First	1.64	0.12	8.88	0.00
	Second	2.66	0.17	34.49	0.00
	Third	1.31	0.20	—	—
2-2	First	1.03	0.18	1.88	0.05
	Second	1.07	0.03	1.84	0.08
2-0	First	0.96	0.34	1.63	0.02
	Second	0.99	0.36	1.60	0.26
	Third	1.13	0.19	—	—
0-2	First	1.57	0.07	3.57	0.22
	Second	1.47	0.11	—	—

Fig. 3. Response rate (pecks per second) by Birds 4 and 5 during white after various orientations of line on green and after green alone during last eight blocks of stimuli in each dimensional control test. Rate after the 90° line is plotted at each end of the tilt dimension. Each panel represents a different combination of training and test trace intervals: 2-0, for example, indicates a 2-sec trace interval during training and a 0-sec trace interval during testing. First, second, and third tests at each combination are represented as circles, triangles, and crosses, respectively.

line-tilt control and degree of interdimensional control during tests is consistent with both notions. However, this correlation was far from perfect. During some tests (*e.g.*, the replication of 2-2 for Bird 4), interdimensional control was near perfect, while line tilt exerted little if any

control over pecking. There thus appears to be some evidence to suggest a true dissociation of inter- and intradimensional control at a longer trace interval. The failure in Experiment I of interdimensional line *versus* no-line training to produce

line-tilt control, and the apparent dissociation of these two forms of control in Experiment II suggest that a line stimulus is multidimensional. In Experiment I, interdimensional training apparently produced control by some dimension of line other than orientation. In Experiment II, the weakening of line-tilt control without a consistent corresponding weakening of line *versus* no-line control suggests that some dimension of line other than orientation was also controlling pecking.

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